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**A multi-spacecraft synthesis of
relativistic electrons in the inner
magnetosphere using
the LANL, GOES, GPS, SAMPEX,
HEO and POLAR spacecrafts**

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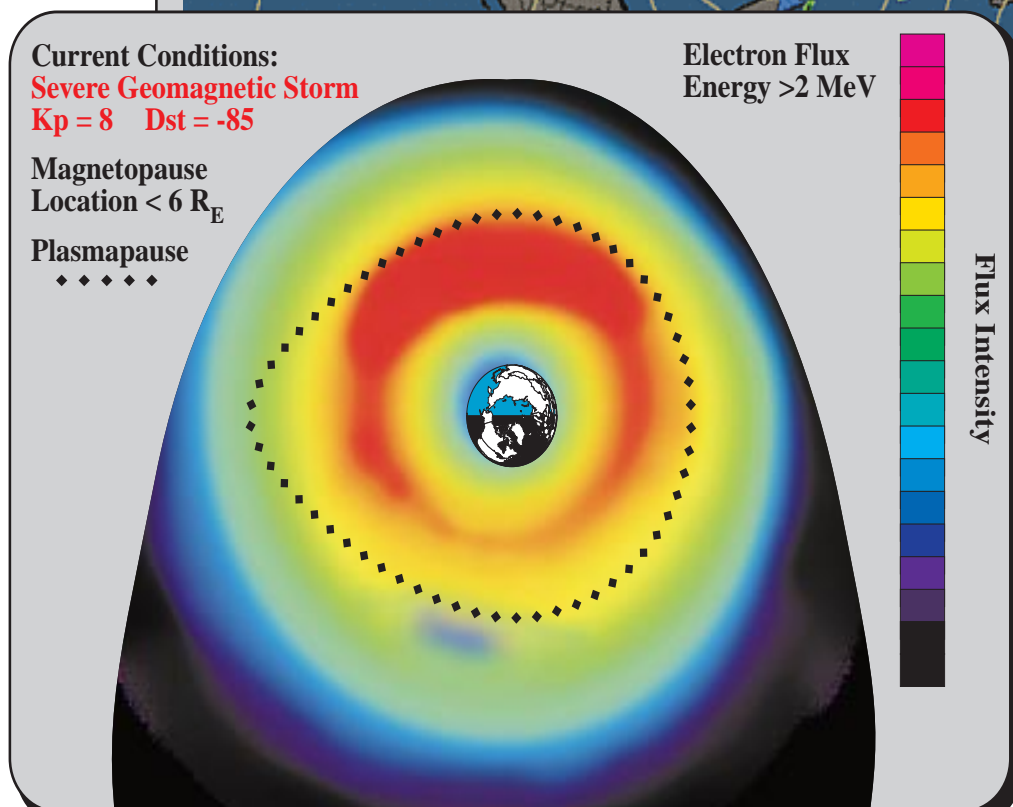
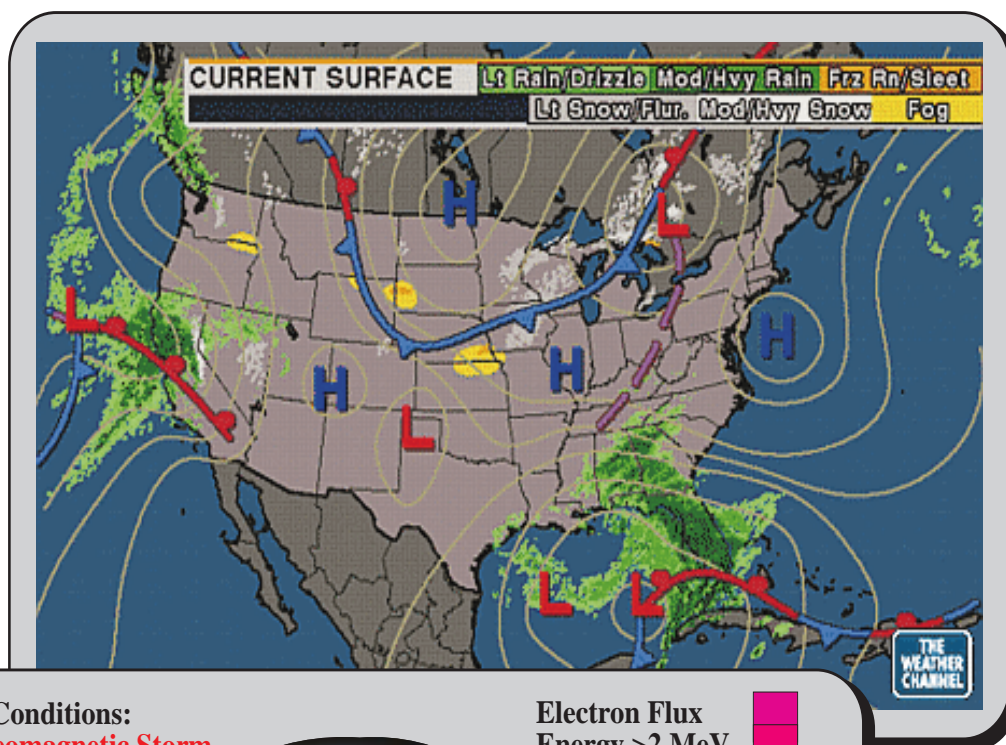
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Overview



1. Many spacecraft are available in the inner magnetosphere capable of measuring relativistic electrons.
2. Possibility of constructing global “snapshots” of the relativistic electron distribution in L and MLT based on data, with a time resolution down to minutes (geostationary) and hours (global).
3. Coverage at other L -values is both spatially and temporally limited.
4. Inter-comparison of data taken at different times, L , Magnetic Latitude and height is difficult, this method explores new ways of presenting multi-satellite data.
5. Application to:
 - (a) Accurate past description of global radiation environment for post event analysis.
 - (b) Inter-calibration of spacecraft data during quiet times.
 - (c) Dynamic periods such as storms to show both the MLT and L transit of injections.
 - (d) Providing realistic global input to diffusive or MHD radiation belt models.

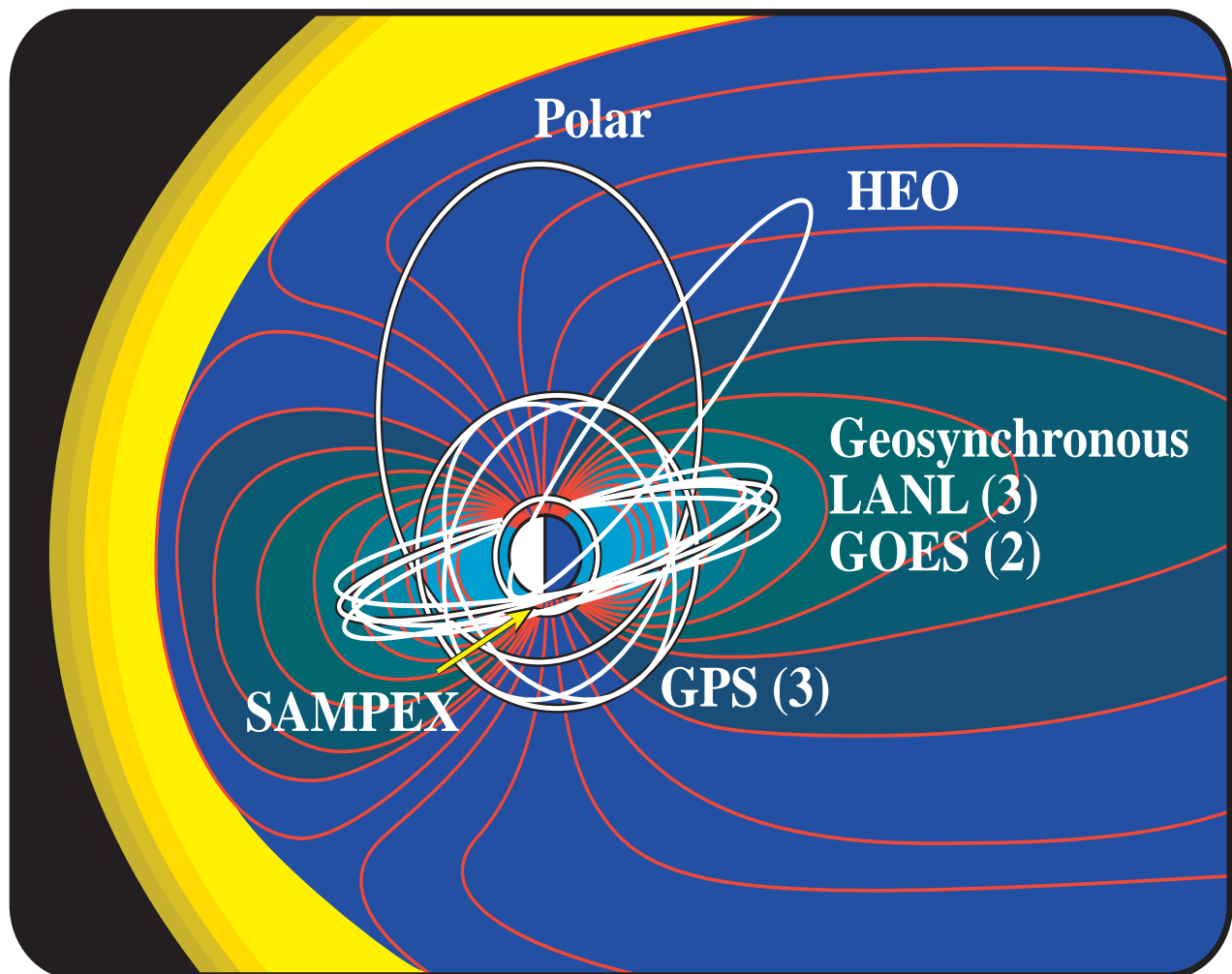
Final Aim: Real Space Weather



Missions



The synthesis is based on “always there” missions such as LANL geostationary and GPS.



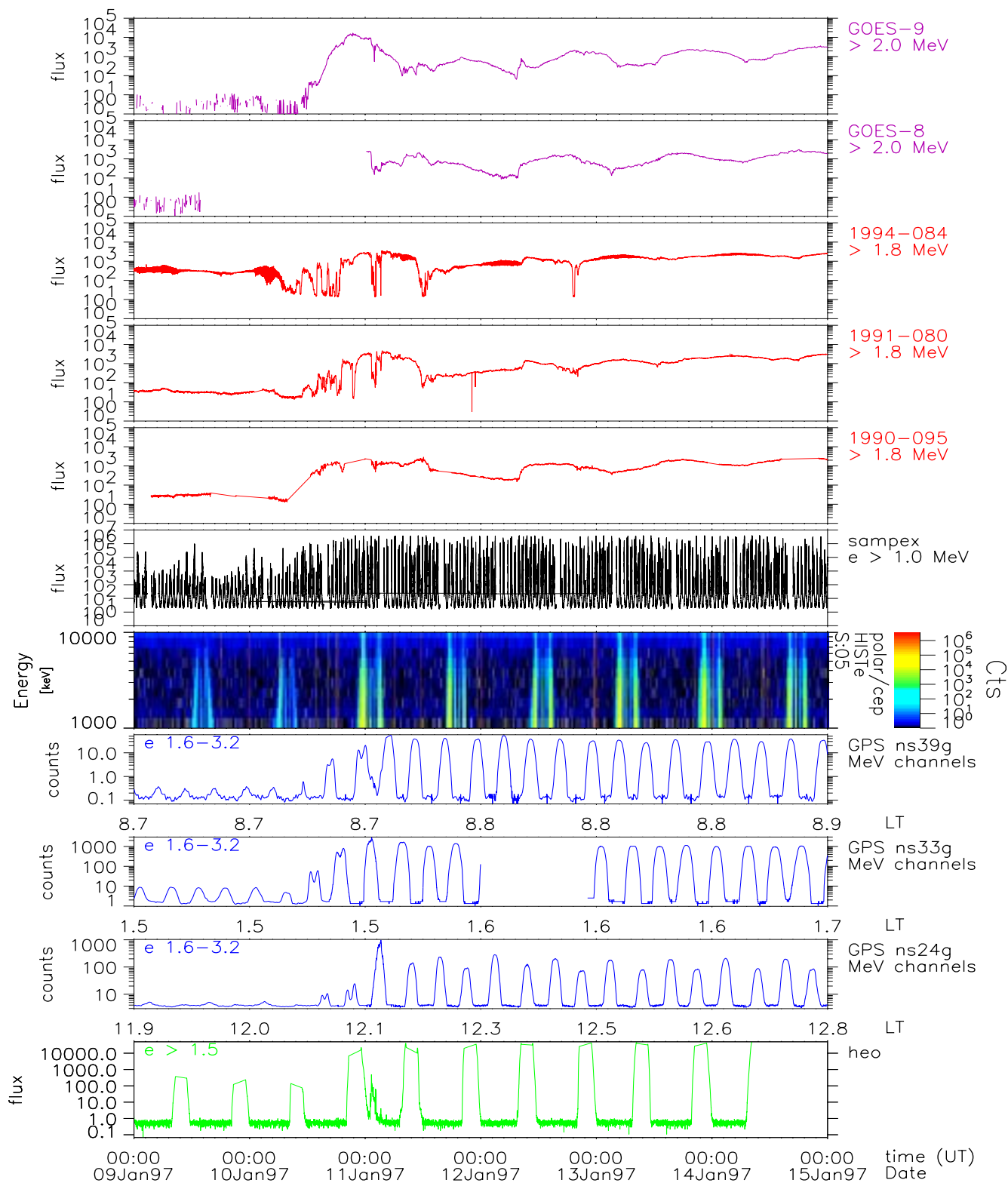
In addition data from “short-lived” missions, such as POLAR, HEO and SAMPEX, can be added when available.

Instrumentation



1. Los Alamos geostationary satellites ESP (Energetic Spectra for Particles) omni-directional flux.
 - 1990-095, 1991-080, 1994-084
 - all > 1.8 MeV electrons
2. GOES geostationary satellites, omni-directional flux.
 - GOES-8, GOES-9
 - all > 2.0 MeV electrons
3. SAMPEX > 1.0 MeV electrons (precipitating flux). 600 km 83° inclination polar orbit.
4. HEO > 1.5 MeV electrons (omni-directional flux). Highly elliptical ($1.1 \times 7 R_e$) 12 hour orbit.
5. POLAR 1.9 – 10 MeV CEPPAD HISTe (omni-directional flux). Polar ($2 \times 9 R_E$) 18 hour orbit,
6. GPS electrons BDD (Burst Detector Dosimeter) (half hemisphere counts). 12 hour geostationary transfer orbit, incl. 45°
 - ns39, ns33, ns24
 - all 1.6 – 3.2 MeV

All data - time series



Method (idealized!) Part A.: Construction of Geostationary Synthesis



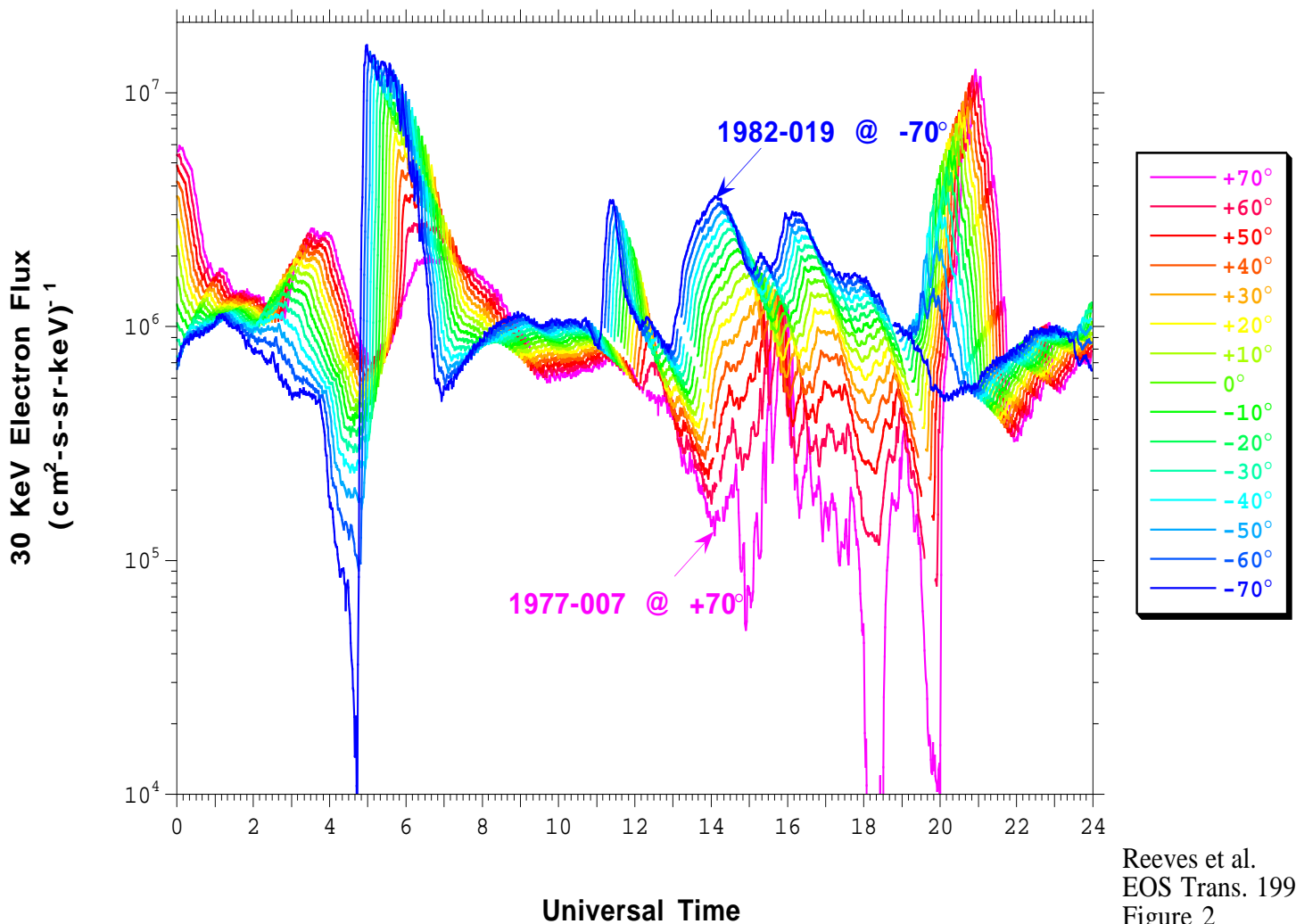
This study is for energetic particle detectors for electrons > 2 MeV.

1. Well calibrated spectra for each satellite are needed. Based on a fit through the discrete or integral channels an equivalent > 2 MeV channel is constructed from each instrument.
2. For all satellites an equivalent set of ordering parameters (L, MLT, MagLat) needs to be constructed based on the SAME magnetic field model.
3. All fluxes need to be transformed to equatorial fluxes using either a theoretical or statistical model.
4. A “base-ring” is constructed at geostationary orbit since here the coverage is most comprehensive (LANL, GOES, UARS):
 - (a) All measurements are scaled to agree at 12 MLT during quiet times.
 - (b) All satellites are assumed to be on the same drift shell.
 - (c) Fluxes are linearly interpolated from satellite to satellite forming a ring of fluxes at $L = 6.6$

Geostationary synthesis: Demonstration of method



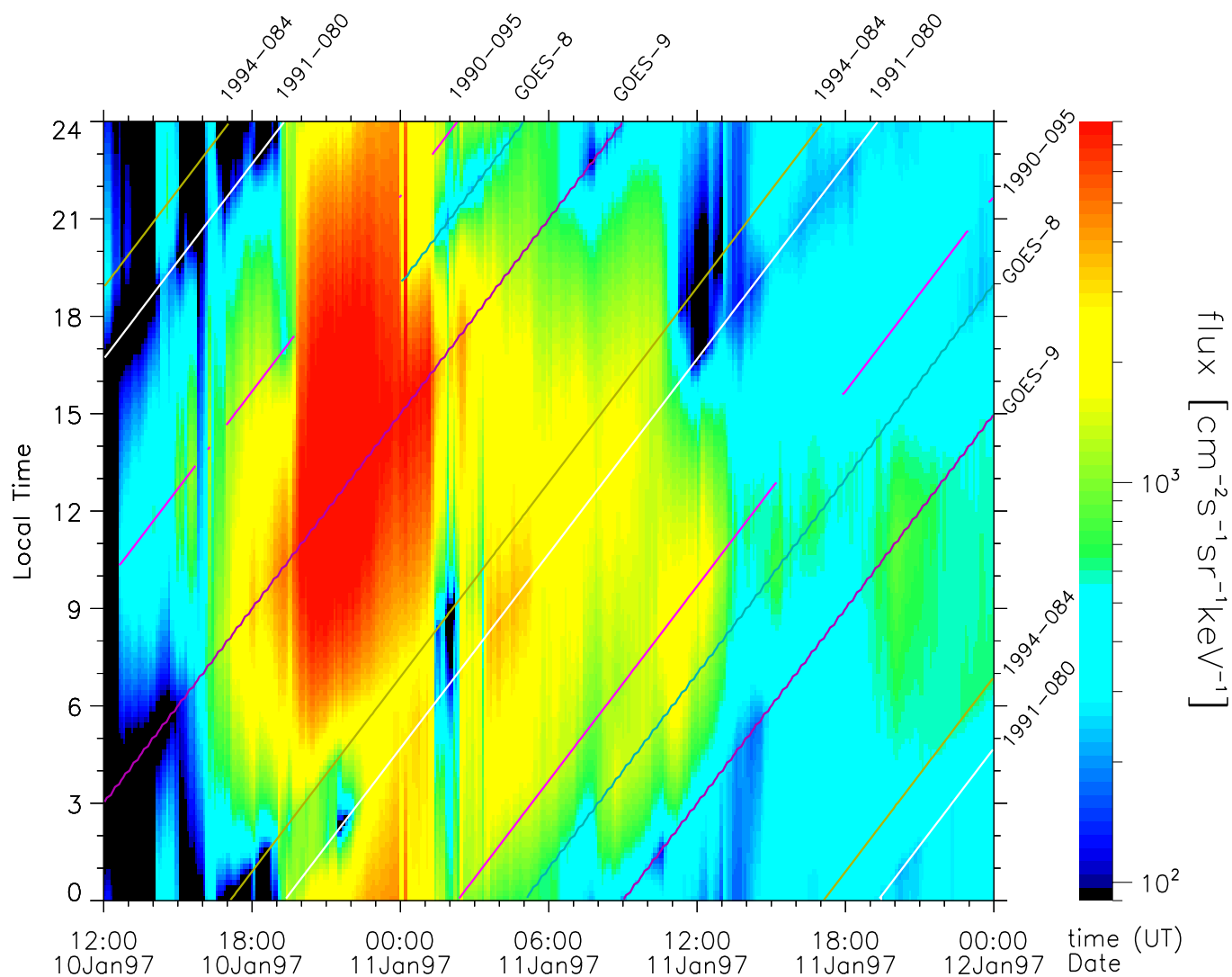
LANL Geosynchronous Energetic Particle Data 10/16/83, Interpolations in Longitude



Reeves et al.
EOS Trans. 1998
Figure 2

Smooth transition of fluxes from one geostationary local time to another.

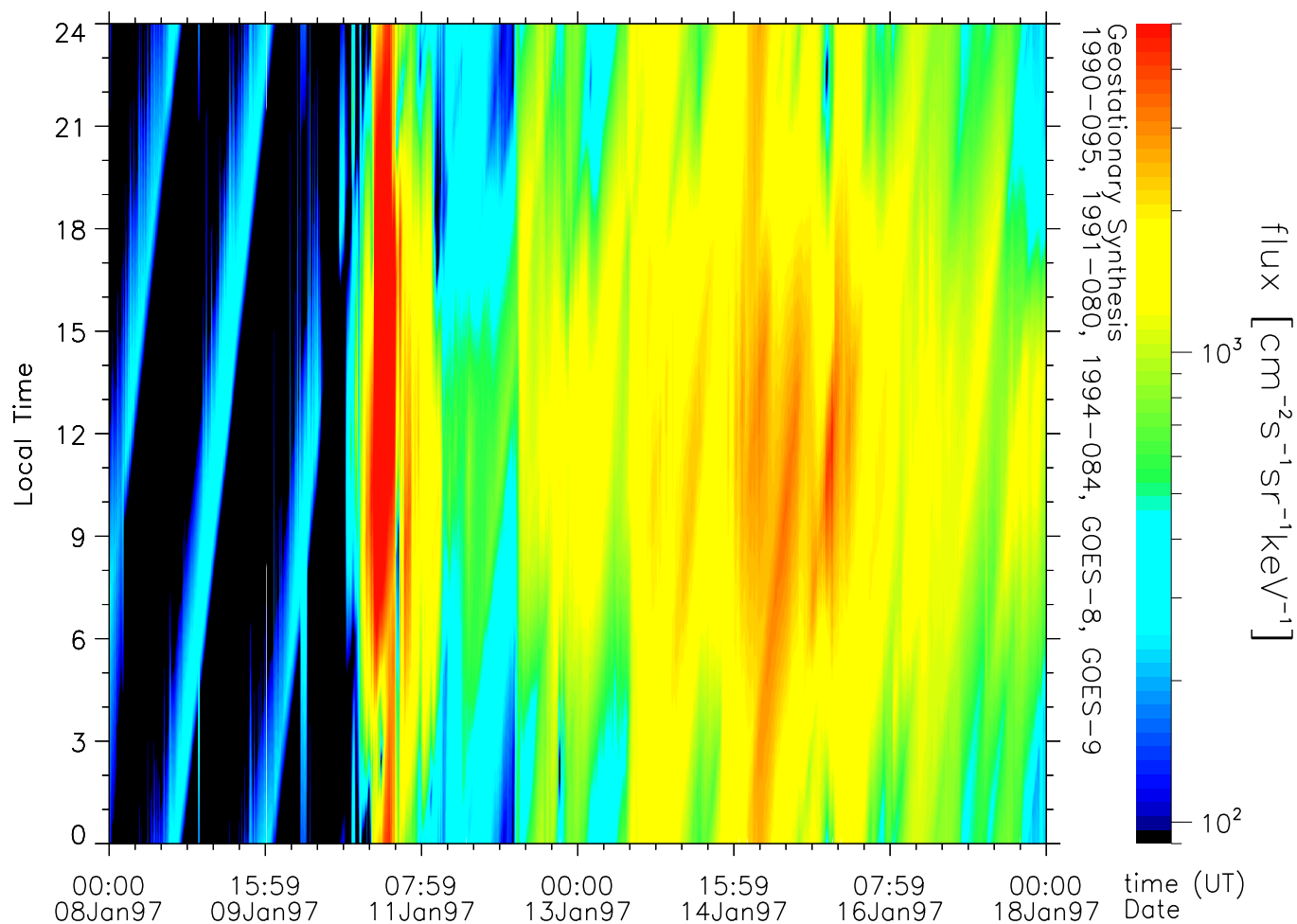
Geostationary synthesis: January 10 1997 initial onset



Results of interpolation between geostationary spacecraft.

5 minute running averages time stepped every minute.

Geostationary synthesis: January 10 1997 delayed response



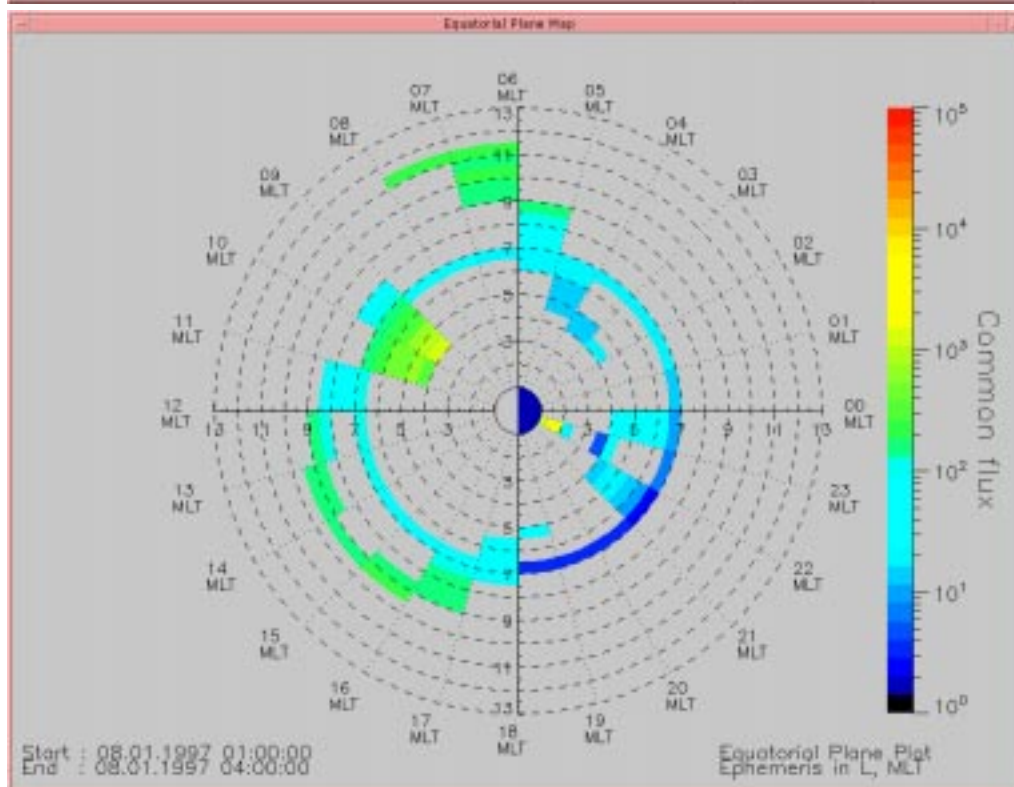
Initial flux increase on January 10 was due to large scale adiabatic compression, followed by the typical delayed flux increase after a few days.

Method (idealized!) Part B: Adding in radial contributions

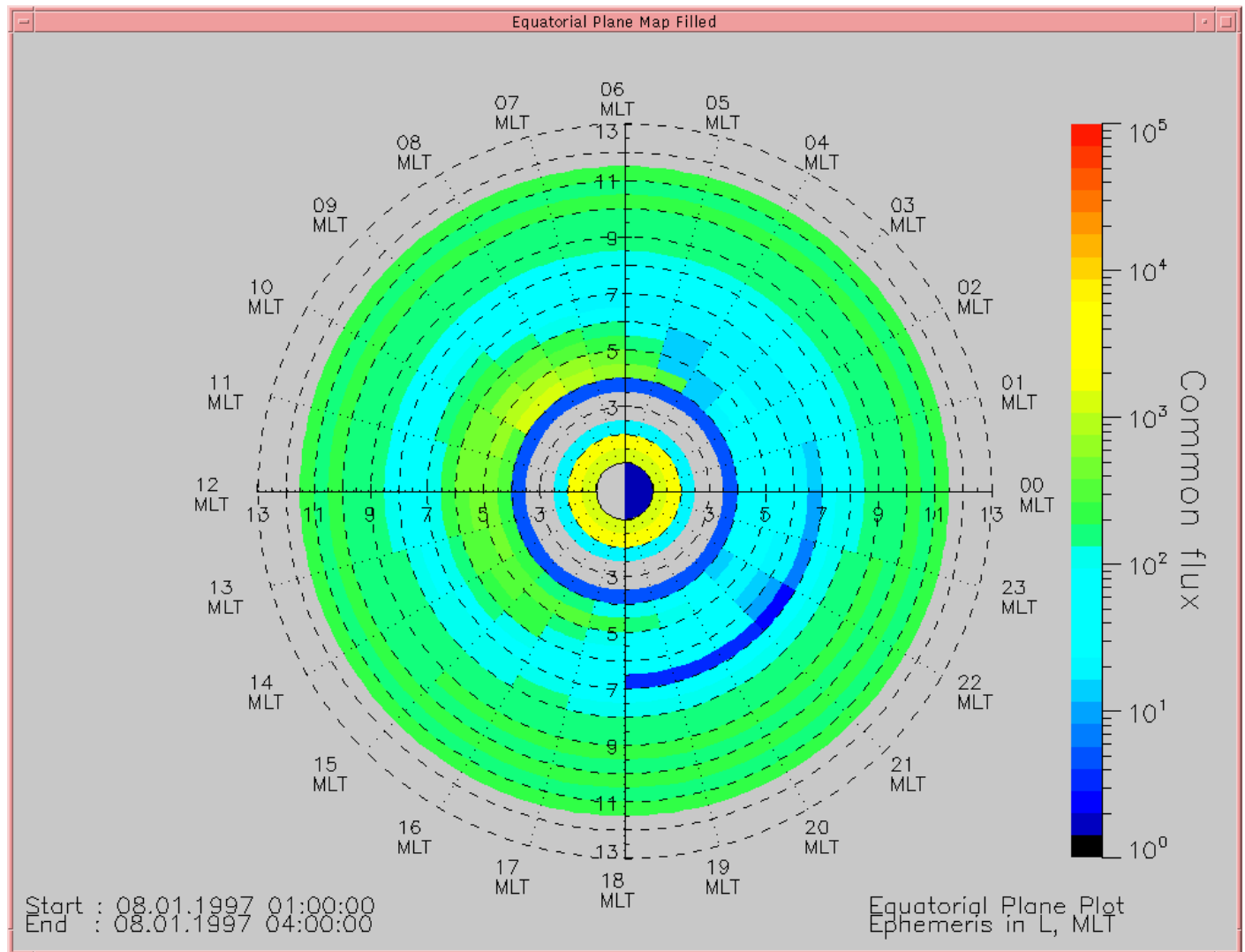


5. All non-geosynchronous satellites are searched for geostationary crossings in the given 3 hour window.
6. Orbits are segmented into individual crossings through L for this time window.
7. Fluxes along each L -slice for are “anchored” at the geostationary base-ring using the geostationary fluxes at that MLT as a reference.
8. Only fluxes above a threshold are used to avoid scaling to each other’s background.
9. Fluxes at all L are interpolated at a given L along MLT between the radial slices forming a complete snapshot at all L , MLT.
10. The process is repeated in increments of 30min.

The final series of “snapshots” can then be viewed as a movie. To increase time resolution, a linear interpolation between such frames in time can be employed.

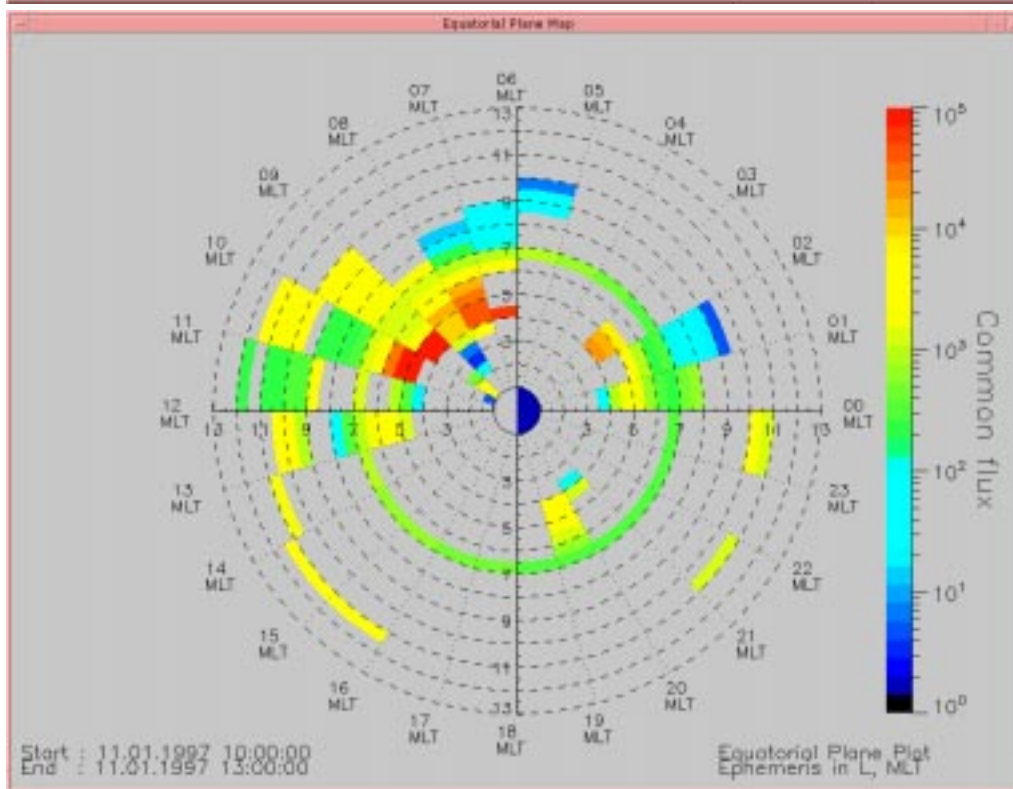


Full synthesis, quiet time: Constructing full map

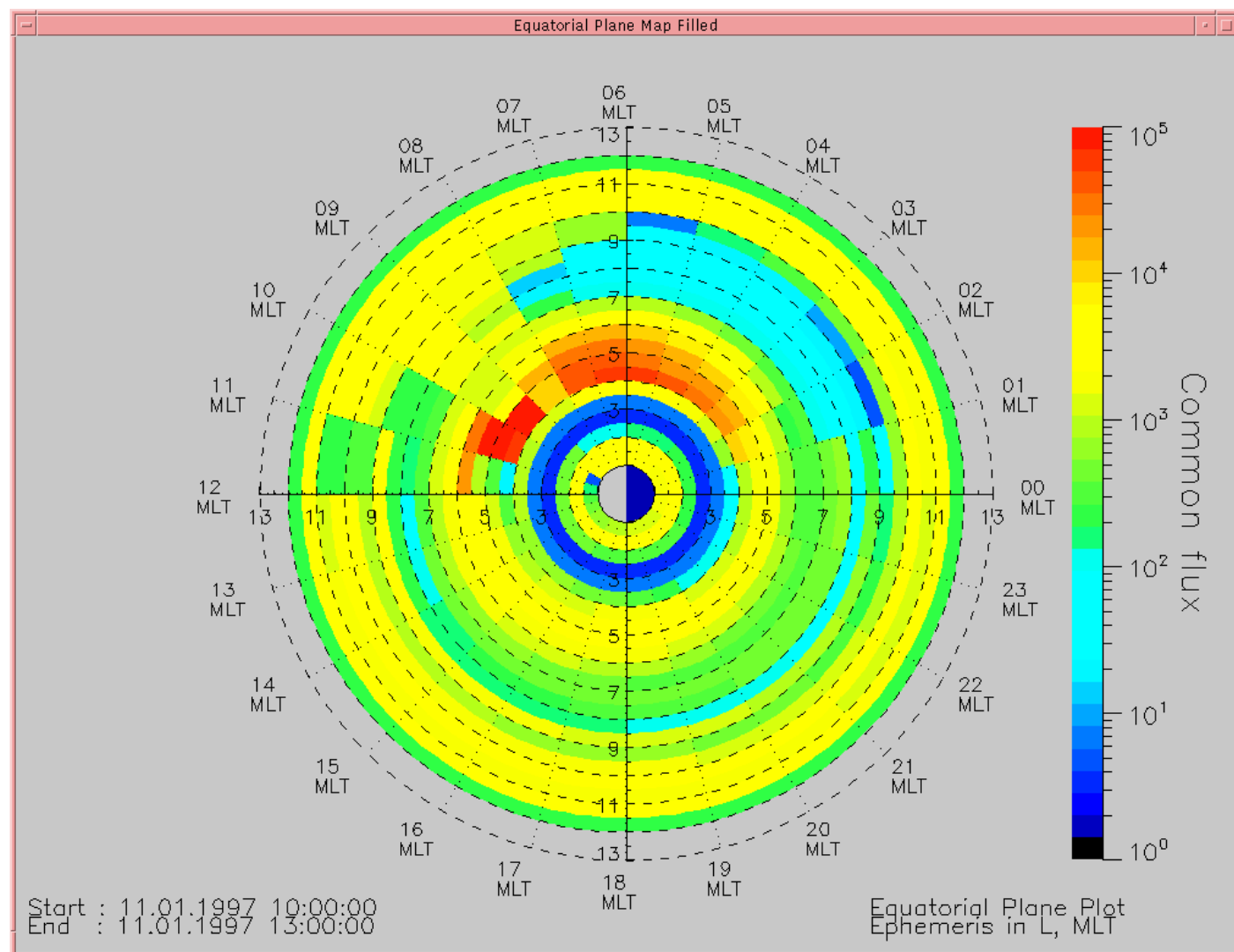


Full map. Actual coverage will vary depending on satellites available during this time.

The increase of flux beyond $L=10$ is instrumental, background mainly in GPS instruments.



Full synthesis, active time: Constructing full map



Full map showing clearly the radiation belt structure and large local time asymmetries in the relativistic electron flux increase.

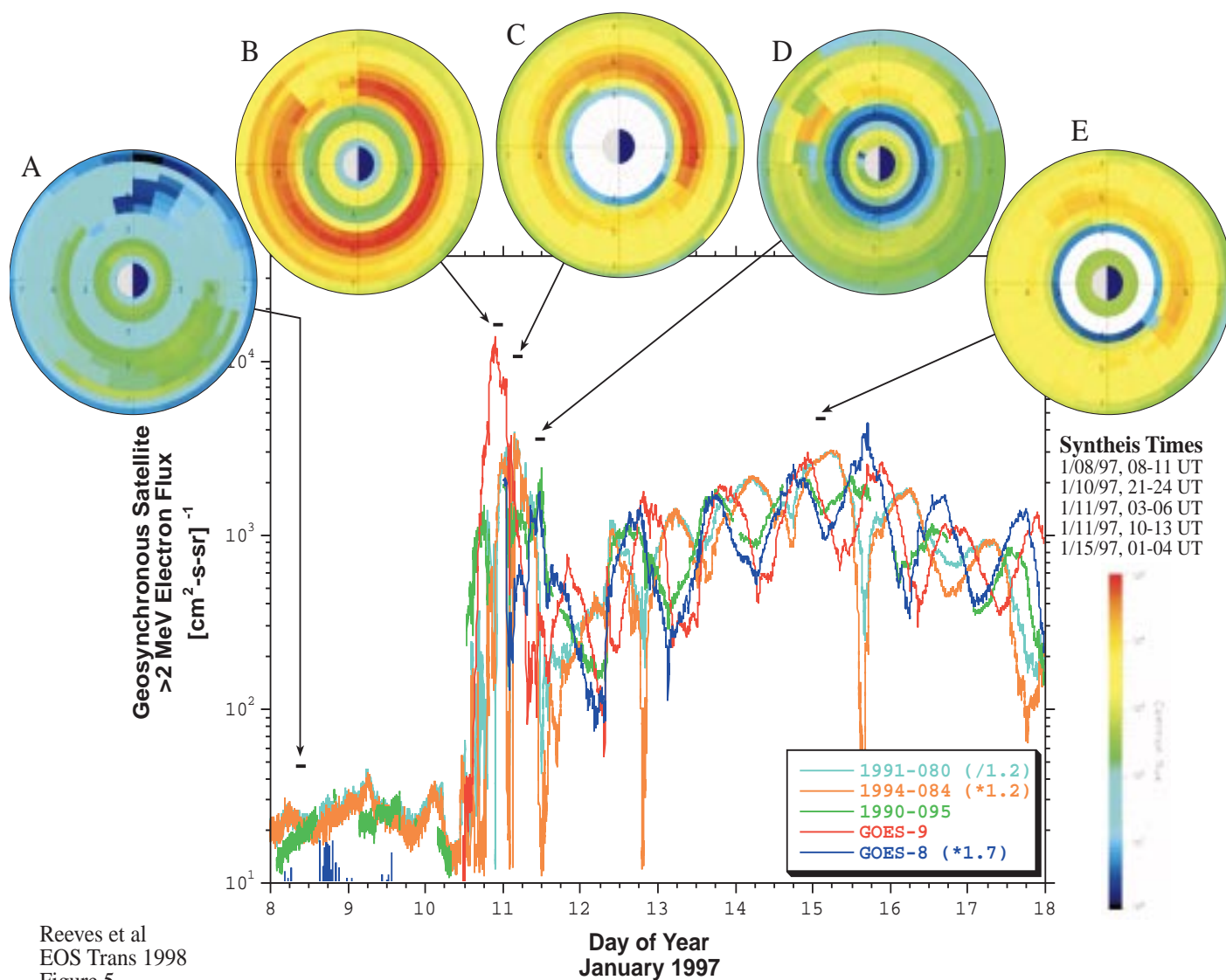
Method (real world)



An initial synthesis was attempted even though not all the conditions of the “idealized” method could be achieved:

1. Only for HEO, SAMPEX, LANL and GOES were the measurements available in fluxes. POLAR fluxes are based on preliminary geometric factors. GPS is in counts.
2. The exact energy range of $> 2MeV$ was only approximated by the nearest integral or differential channel available. For none of the instruments a fully calibrated spectral fit was available.
3. Calculation of common magnetic field parameters for all satellites has not been performed yet. L values as delivered with the data were used (probably from a range of models!). For SAMPEX, L was calculated based on a simple dipole model. For the geostationary satellites LT was used instead of MLT, and a fixed L of 6.6 was used.
4. transformation of fluxes to equatorial where all done on the assumption of omni-directional flux, flat pitch angle distribution, scaling by B/B_o . This is especially problematic for SAMPEX.

More insights with this method



This synthesis offers a unique way of making sense of multi-spacecraft data!

Results - Conclusions?



1. The synthesis method is a viable way to obtain global, data-based maps of the radiation environment in the inner magnetosphere, ideally suitable for post-event analysis.
2. Extension to a near-real time system is in principle possible (based on LANL, GOES and GPS only).
3. Limitations are accepted at this stage of the synthesis model. Refinements are of course infinitely possible:
 - (a) Use of consistent and better magnetic field models.
 - (b) Many instruments need a calibrated > 2 MeV channel.
 - (c) Better mapping algorithm between observed fluxes and the reference equatorial plane (theoretical model such as SALAMMBO; statistical model such as AE-8, AP-8 or CRRESstat). Establishing a data base of mapping factors from $\text{flux}(\text{MagLat}, L) \longrightarrow \text{flux}(\text{equatorial}, L)$.
4. Add in more satellites!

Improved coverage



The time resolution possible with the model depends on the total given coverage for a given time range:

- Sampex is currently the only satellite covering the inner zone below $L = 4$. It has a high time resolution for L-traverses and is crucial to add into the global synthesis.
- To improve the time resolution possible for full equatorial flux maps we're looking forward to having the full compliment of 12 GPS satellites with space environment monitors.
- Using both HEO spacecraft routinely (same orbit, different phase). Data access here is limited through The Aerospace Corporation.
- EQUATOR-S has some limited data for it's lifetime (Nov 97 – April 98), which will be in an elliptical, near-equatorial orbit with an 11 Re apogee and 500km perigee.
- Add environmental monitors to as many other spacecraft as possible! Off-the-shelf units & expertise are available!